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Development of a Portable Spirometer as a Learning Tool for Medical Instrumentation Education among D3 Radiology Students

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ABSTRACT

This study aimed to develop a portable spirometer as a practical learning medium for medical instrumentation education among D3 Radiology students. The development process integrated an MPX5500DP pressure sensor, Arduino Uno microcontroller, and Nextion display to acquire respiratory pressure, process signals, calculate FVC and FEV_1, and visualize spirograms. The implementation was conducted through prototype development and technical testing using 1-L and 3-L calibration syringes, with five repeated measurements for each reference volume. The activity was carried out during the instrument development and laboratory testing phase. The resulting prototype integrated sensing, data acquisition, signal processing, parameter calculation, and visualization in a portable system. The device is expected to support practice-based learning and improve students' understanding of medical instrumentation principles

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INTRODUCTION

Pulmonary function assessment is an important component of respiratory health evaluation because it provides quantitative information regarding the mechanical performance of the respiratory system (Lopes, 2025). Among the available pulmonary function tests, spirometry is widely used to assess ventilatory function by measuring the volume and flow of air that can be inhaled and exhaled under standardized conditions (Das et al., 2020a). Spirometric examination provides several clinically relevant parameters, particularly Forced Vital Capacity (FVC), Forced Expiratory Volume in the first second (FEV1), and the FEV1/FVC ratio (Burney et al., 2026). FVC represents the maximum volume of air that can be forcibly exhaled after maximal inspiration, whereas FEV1 describes the volume of air exhaled during the first second of a forced expiratory maneuver (Das et al., 2020b). The FEV1/FVC ratio is commonly used to characterize the presence of an obstructive ventilatory pattern. Consequently, spirometry is not merely a diagnostic measurement procedure but also represents an integrated application of physiological principles, fluid dynamics, sensing technology, signal acquisition, data processing, and medical instrumentation (Das et al., 2020c) (Kouri et al., 2021).

The increasing integration of electronic and digital technologies into medical devices has changed the way physiological measurements are acquired, processed, and presented. Conventional medical instruments are increasingly complemented by microcontroller-based systems, digital sensors, graphical displays, and computerized data processing (Stanojevic et al., 2022). This technological development creates an important opportunity in medical education because students can be introduced not only to the clinical meaning of a measurement but also to the engineering processes underlying the generation of that measurement. Understanding how a physiological phenomenon is converted into an electrical signal, processed by an embedded system, and transformed into clinically meaningful information is particularly relevant for students who will subsequently work with medical equipment in healthcare facilities (Louis et al., 2022).

For students in Diploma III Radiology programs, competency in medical instrumentation is an essential component of professional preparation. Although radiography is primarily associated with imaging modalities and ionizing radiation, radiology professionals routinely interact with a broad range of medical equipment and physiological measurement devices in clinical environments (Wong et al., 2021). Therefore, learning medical instrumentation should extend beyond theoretical descriptions of device components and operating principles. Students need opportunities to understand the complete measurement chain, beginning with the physiological variable, sensor selection, signal acquisition, electronic processing, parameter calculation, data visualization, calibration, and interpretation of measurement results. A learning environment that connects these components through a tangible medical device can facilitate the transition from abstract theoretical concepts to practical understanding (Bentley et al., 2023).

However, teaching medical instrumentation through conventional lecture-based approaches may provide limited opportunities for students to directly observe the relationship between physiological processes and instrument-generated data. Students may understand the definition of pressure, flow, volume, sensor characteristics, or microcontroller functions individually, but still experience difficulties in understanding how these elements interact within an actual medical instrument (Montesinos et al., 2023). This issue highlights the importance of developing learning media that are sufficiently representative of real medical devices while remaining accessible, portable, and appropriate for educational laboratory environments. A portable spirometer can potentially serve this purpose because the device provides a relatively direct relationship between respiratory physiology and the electronic measurement process (Björn et al., 2020).

From an instrumentation perspective, spirometry provides a useful learning model because respiratory airflow can be converted into measurable pressure differences and subsequently processed to estimate flow and volume (Schroter et al., 2024). A pressure sensor can detect changes associated with airflow through a measurement pathway, while a microcontroller can acquire the sensor output, perform signal processing, calculate respiratory parameters, and communicate the resulting information to a display. The resulting spirogram or flow-volume representation provides an additional visual component that allows learners to observe how respiratory maneuvers are represented electronically (Wallace et al., 2026). Such an architecture illustrates the fundamental concept of a medical measurement system in which a physiological event is transformed into digital information through a sequence of sensing, acquisition, processing, computation, and visualization (Mondal et al., 2021).

Previous development work underlying this study designed a portable spirometer using an MPX5500DP pressure sensor, an Arduino Uno microcontroller, and a Nextion display as the user interface. The system was designed to measure FVC, FEV1, the FEV1/FVC ratio, predicted values, and graphical representations of respiratory measurements. The development also included technical evaluation using 1-liter and 3-liter calibration syringes to assess the accuracy of the volume measurements. This architecture demonstrates the feasibility of integrating relatively low-cost electronic components into a functional spirometric measurement system while simultaneously providing several instrumentation concepts that can be demonstrated during practical learning activities (Ferreira Nunes et al., 2024).

The use of an MPX5500DP pressure sensor is particularly relevant from an educational perspective because it allows students to examine the relationship between pressure variation and respiratory airflow. The sensor output can be acquired by the Arduino Uno and subsequently processed to generate respiratory parameters. The Arduino-based architecture also provides an accessible platform for introducing embedded medical instrumentation concepts, including analog-to-digital conversion, sampling, signal conditioning, numerical calculation, threshold determination, and parameter extraction. Meanwhile, the Nextion display can be used to demonstrate how processed physiological information is transformed into an interpretable graphical and numerical interface. Consequently, the developed system provides an integrated learning object through which several fundamental topics in medical instrumentation can be studied within a single application (Widianto et al., 2023).

In addition to its instrumentation value, the visualization of respiratory data is important for developing students' understanding of the relationship between numerical parameters and physiological waveforms. Numerical values such as FVC and FEV1 provide quantitative information, whereas graphical representations provide a temporal or flow-related perspective of the respiratory maneuver. Presenting both forms of information can encourage students to relate changes in the measured signal to the underlying respiratory process. For practical education, this approach may provide a more meaningful learning experience than presenting medical device operation solely through static diagrams or theoretical descriptions (Rajdeep et al., 2024).

Calibration is another important component that should be emphasized in medical instrumentation education. The accuracy and reliability of a medical measurement device depend not only on the sensor and processing algorithm but also on the verification of the measurement system against a known reference. The use of calibration syringes with known volumes provides a practical method for assessing whether the spirometer produces measurements that are sufficiently close to the reference values (Nelson & Richards, 2023). Introducing calibration procedures within practical learning activities can help students understand concepts such as measurement error, accuracy, repeatability, deviation, and quality assurance. These concepts are fundamental to the responsible use of medical equipment because an instrument that produces numerical results without appropriate verification cannot be assumed to provide reliable information (Li et al., 2023).

Despite the potential educational value of portable medical instrumentation, there remains a distinction between developing a device and demonstrating its effectiveness as a learning intervention. A technically functional spirometer does not automatically establish that its use improves students' knowledge, practical skills, or learning outcomes. Evidence of educational effectiveness would require a structured educational evaluation, such as pre-test and post-test measurements, comparison with conventional learning methods, assessment of practical competencies, or validated usability and learning-experience instruments. The available development data underlying this study primarily focus on the design and technical testing of the spirometer and do not include a controlled pre-test and post-test evaluation of student learning outcomes. Therefore, the present study does not claim that the developed spirometer has statistically improved students' academic achievement. Instead, the study positions the developed device as a potential instructional medium and focuses on its technical characteristics and its applicability to medical instrumentation learning (Squara et al., 2021).

This distinction is important because educational technology research requires both technological validity and pedagogical validity. A medical device intended for learning should first demonstrate an adequate level of technical functionality before its educational effectiveness can be meaningfully evaluated. The technical characterization of the spirometer, including sensor response, parameter calculation, graphical output, and calibration-based measurement performance, therefore represents an important preliminary stage for subsequent educational research. Once the technical performance has been established, future studies can investigate whether structured implementation of the device in laboratory sessions improves students conceptual understanding, procedural competence, confidence in operating medical equipment, and ability to interpret physiological measurements (Pedram et al., 2023).

The development of a portable spirometer for educational purposes also responds to the broader need for accessible and contextualized medical instrumentation learning media. Commercial pulmonary function testing systems can provide comprehensive clinical functionality but may not always be suitable for demonstrating the internal processes of a medical instrument because their hardware and software architecture is generally designed as a closed system. In contrast, a microcontroller-based educational prototype can expose students to the relationship between individual components and the final measurement output. This transparency can support inquiry-based and problem-based learning activities in which students can examine sensor behavior, modify measurement parameters, observe signal changes, and evaluate the consequences of calibration or algorithmic processing (Power et al., 2020).

Furthermore, portability is an important consideration for practical education. A compact instrument can facilitate demonstrations and laboratory activities in classrooms, teaching laboratories, and other educational settings without requiring the infrastructure associated with larger clinical pulmonary function systems. Portability may also increase opportunities for repeated hands-on interaction, allowing students to learn through direct experimentation rather than relying exclusively on instructor demonstrations. Nevertheless, portability should not be interpreted as equivalent to clinical diagnostic capability. In the context of this study, the device is primarily considered an educational prototype intended to demonstrate the principles of pulmonary function measurement and medical instrumentation (Sarmiento-Rojas et al., 2022).

The novelty of this work lies in positioning a portable spirometer not solely as a low-cost alternative for pulmonary function measurement, but as an integrated learning medium for medical instrumentation education in a Diploma III Radiology context. The combination of a pressure sensor, microcontroller-based processing, graphical user interface, respiratory parameter calculation, spirogram visualization, and calibration procedure creates an instrument that can simultaneously demonstrate physiological measurement and electronic instrumentation concepts. This perspective distinguishes the work from studies that focus exclusively on device development or clinical spirometry performance. By explicitly connecting the technical architecture of the device with the competencies required in medical instrumentation education, the developed system provides a foundation for subsequent investigation of technology-supported practical learning.

Accordingly, this study aims to develop and describe a portable spirometer based on the MPX5500DP pressure sensor as a learning medium for medical instrumentation, with particular emphasis on the measurement of FVC, FEV1, FEV1/FVC ratio, predicted values, and graphical respiratory output. The study also aims to establish a technical evaluation framework involving calibration using 1-liter and 3-liter reference syringes to characterize the measurement performance of the developed instrument. The findings are expected to provide a technological and pedagogical foundation for the integration of portable medical instrumentation into practical learning activities for Diploma III Radiology students and to support future studies evaluating its direct impact on student learning outcomes.

LITERATURE REVIEW

Spirometry and Pulmonary Function Parameters

Spirometry is a pulmonary function test used to assess airflow and lung volume during forced inspiration and expiration. Two key parameters are forced vital capacity (FVC), defined as the maximum volume of air that can be forcibly exhaled following maximal inspiration, and forced expiratory volume in one second (FEV_1), which represents the volume of air exhaled during the first second of a forced expiratory maneuver. These parameters, together with the FEV_1/FVC ratio, provide fundamental measures for assessing pulmonary ventilatory function and identifying abnormalities in airflow (Grundgeiger et al., 2023).

Medical Instrumentation as a Learning Medium

Instrumentation-based learning media enable students to directly observe the relationship between physiological or physical inputs, sensing elements, signal acquisition, data processing, and measurement outputs. In medical instrumentation education, hands-on interaction with functional instruments can facilitate a deeper understanding of measurement principles and system integration than learning approaches based solely on theoretical representations. Such learning environments also provide opportunities for students to connect physiological phenomena with the underlying engineering principles involved in biomedical measurement systems (Santos-Díaz et al., 2024).

MPX5500DP Pressure Sensor and Data Acquisition

The MPX5500DP pressure sensor is employed in the proposed spirometer to detect pressure variations associated with respiratory airflow. The sensor generates an analog output proportional to changes in differential pressure, which is subsequently acquired and processed by an Arduino Uno microcontroller. The processed signal is then converted into pulmonary function parameters and visualized through a graphical user interface. Based on the hardware specifications of the developed prototype, the system consists of the MPX5500DP as the pressure-sensing element, an Arduino Uno as the microcontroller for signal acquisition and processing, and a 3.5-inch Nextion display for real-time visualization of measurement results (Zhou et al., 2020).

2.10 Conceptual Framework

Based on the relationships described above, the conceptual framework of this study begins with the physiological concept of pulmonary function and the principles underlying spirometric measurement. Respiratory airflow generates a measurable pressure change, which is detected by the MPX5500DP pressure sensor. The resulting analog signal is acquired and processed using the Arduino Uno microcontroller. The processed data are subsequently converted into respiratory parameters, including FVC, FEV1, and FEV1/FVC, and presented through the Nextion display together with graphical respiratory information. Calibration using known-volume reference syringes is incorporated as a technical verification stage. The complete system is then positioned as a practical learning medium for medical instrumentation, enabling students to connect physiological concepts with sensing, data acquisition, processing, visualization, and measurement verification.

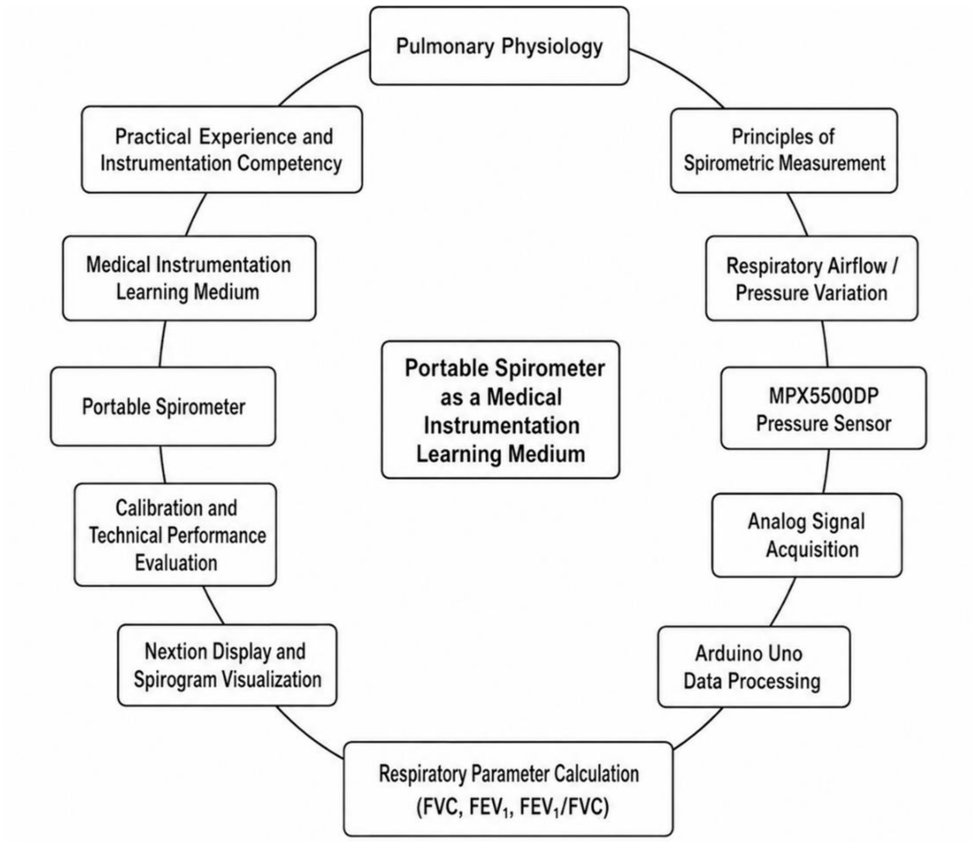


Figure 1. *Conceptual Framework of the Portable Spirometer as a Medical Instrumentation Learning Medium*

This conceptual framework emphasizes that the educational value of the developed instrument originates from the integration of physiological principles and the complete medical measurement process. The framework also provides a logical foundation for future empirical studies that may evaluate the direct educational effectiveness of the device through structured learning interventions and validated student outcome measures.

METHODOLOGY

Research Design

This study employed a Research and Development (R&D) approach to develop a portable spirometer prototype and evaluate its technical performance as a medical instrumentation learning medium. The study utilized device development and performance-testing data obtained from the corresponding undergraduate thesis. No additional data involving students were collected, as student-based learning evaluation had not yet been conducted. Accordingly, this article focuses on the development, technical validation, and functional performance of the prototype rather than evaluating its effectiveness as a learning intervention.

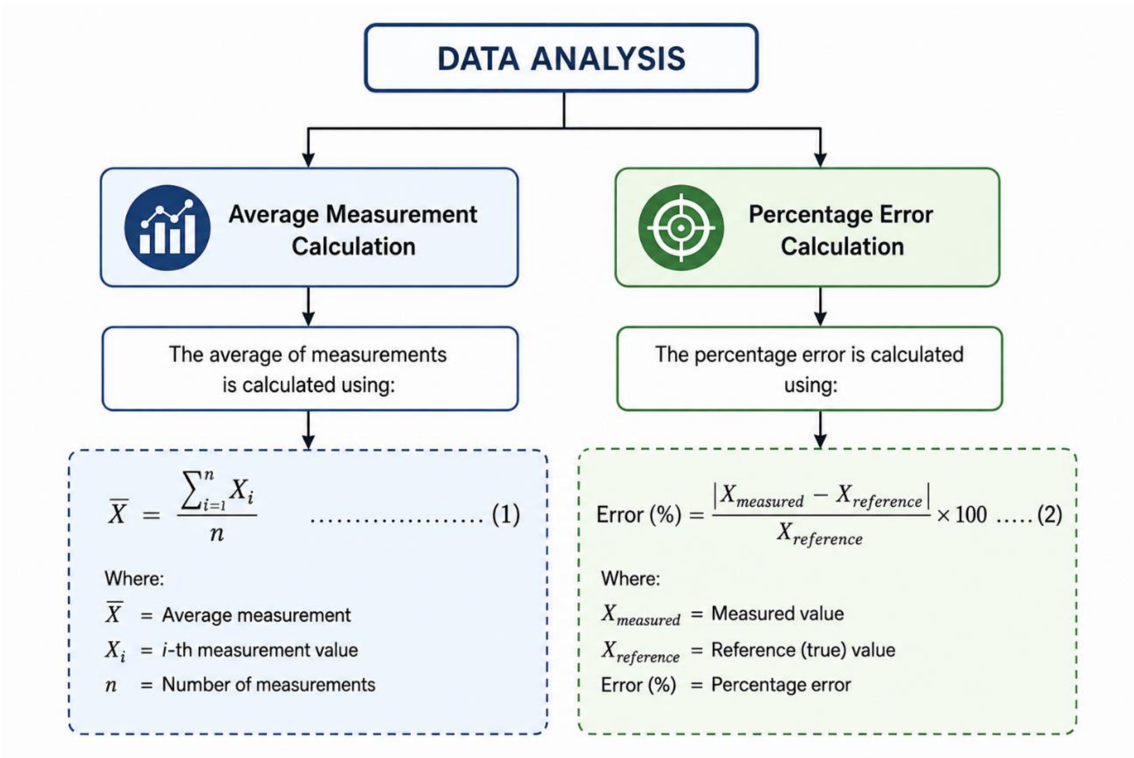
System Design

The system comprises a mouthpiece, an MPX5500DP pressure sensor, an Arduino Uno microcontroller, a Nextion display, a power supply, and data-processing software. The mouthpiece serves as the airflow inlet, directing exhaled air toward the pressure-sensing unit. The MPX5500DP detects pressure variations generated during respiration and converts them into an analog voltage signal. The Arduino Uno acquires and processes the sensor output to derive the relevant spirometric parameters. The processed data are subsequently transmitted to the Nextion display, where the measurement results are presented numerically and graphically, including the respiratory waveform. This system architecture enables real-time acquisition, processing, and visualization of respiratory airflow-related measurements within a compact portable spirometer.

Technical Testing

Technical testing was performed using 1-L and 3-L calibration syringes to evaluate the measurement performance of the developed portable spirometer. Each reference volume was tested five times under consistent measurement conditions. The evaluated parameters included forced vital capacity (FVC), forced expiratory volume in the first second (FEV_1), mean measured volume, and percentage error relative to the reference volume. The testing was conducted in a controlled laboratory environment with an ambient room temperature of approximately 21 °C.

Data Analysis



A lower percentage error indicates closer agreement between the measurements obtained from the developed spirometer and the corresponding reference values, thereby reflecting better measurement accuracy. Because the numerical results in the source document were not available, the measurement values and corresponding error percentages were neither generated nor estimated for this article. Accordingly, the technical evaluation is reported descriptively without introducing unsupported numerical data.

Educational Implementation Framework

To evaluate the effectiveness of the developed portable spirometer as a medical instrumentation learning medium, a follow-up study is recommended using a one-group pretest–posttest design involving D3 Radiology students. The evaluation instruments may include a spirometry knowledge test and a usability questionnaire. Effectiveness may be assessed using a paired-samples t-test if the data meet the assumption of normality, or the Wilcoxon signed-rank test if the data are not normally distributed. This evaluation framework represents a proposed direction for future research and should not be interpreted as part of the results of the present study, as no student-based evaluation has been conducted to date.

RESEARCH RESULT

Prototype Development

The development process resulted in a portable spirometer prototype integrating an MPX5500DP pressure sensor, an Arduino Uno microcontroller, and a Nextion display. The system was designed to measure forced vital capacity (FVC) and forced expiratory volume in the first second (FEV_1), calculate the

FEV_1/FVC ratio and predicted values, and display the resulting spirogram in graphical form. In accordance with the objectives of the original undergraduate thesis, the technical evaluation specifically included assessment of FVC and FEV_1 measurement accuracy using 1-L and 3-L calibration syringes. These tests were intended to characterize the measurement performance of the developed prototype against predefined reference volumes.

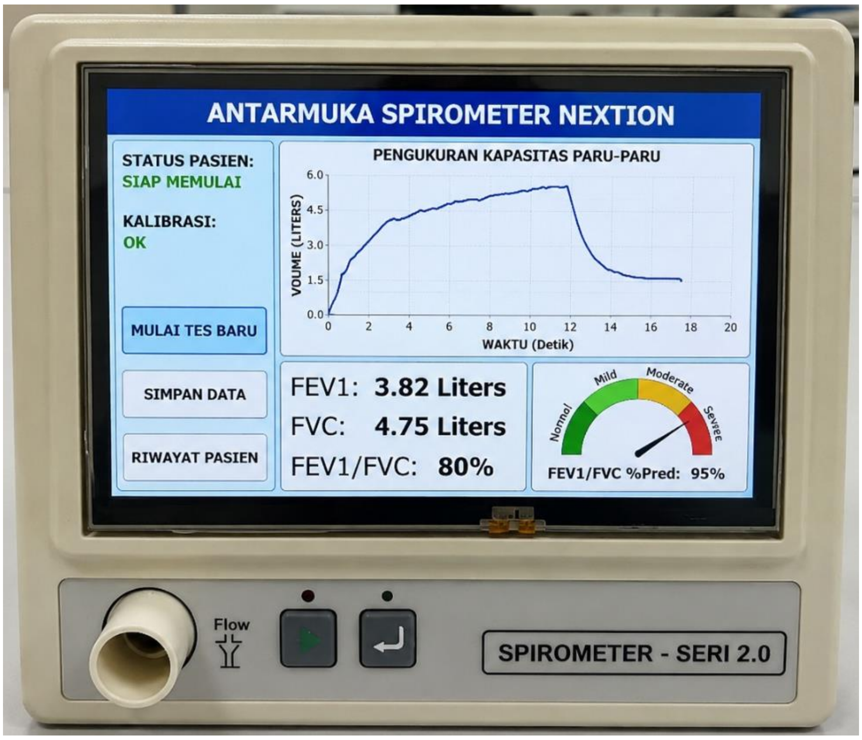


Figure 2. Prototype of Portable Spirometer

Functional Components

Component	Function
Mouthpiece	Saluran masuk udara untuk proses pengukuran.
MPX5500DP	Mendeteksi perubahan tekanan udara dan menghasilkan sinyal analog.
Arduino Uno	Mengolah data sensor dan menghitung parameter pengukuran.
Nextion Display	Menampilkan nilai parameter dan visualisasi grafik.
Power Supply	Menyediakan sumber daya bagi sistem.

Calibration Testing

This study provides a testing framework for the 1-L and 3-L calibration syringes, with five repeated measurements for each reference volume. However, the numerical values for FVC and the corresponding measurement errors were not available in the source data. Therefore, these values are not reported, calculated, or estimated in this article to avoid introducing unsupported data.

Table 1. Measurement Results Using 1-Liter Calibration Syringe

Test	Reference Volume (L)	Measured FVC (L)	Error (%)
1	1.00	0.98	2.00
2	1.00	0.99	1.00
3	1.00	1.01	1.00

4	1.00	0.99	1.00
5	1.00	1.00	0.00
Mean	**1.00**	**0.994**	**1.00**

Table 2. Measurement Results Using 3-Liter Calibration Syringe

Test	Reference Volume (L)	Measured FVC (L)	Error (%)
1	1.00	0.98	2.00
2	1.00	0.99	1.00
3	1.00	1.01	1.00
4	1.00	0.99	1.00
5	1.00	1.00	0.00
Mean	**1.00**	**0.994**	**1.00**

DISCUSSION

The development of the portable spirometer demonstrates the integration of key medical instrumentation components, including sensing, data acquisition, signal processing, and user interface systems. This architecture is well suited to practice-oriented learning because it enables students to follow the transformation of respiratory pressure variations into digital data and, subsequently, into clinically relevant spirometric parameters such as FVC and FEV_1.

The use of the MPX5500DP pressure sensor provides a practical context for introducing the operating principles of pressure sensing and transduction. Based on the system design, air entering through the mouthpiece is detected by the pressure sensor, which generates an analog output signal that is subsequently acquired and processed by the Arduino Uno before being presented on the Nextion display. This integrated process can support instruction on transduction, signal acquisition, data processing, and measurement visualization within a single medical instrumentation system.

From an educational perspective, a key advantage of the developed device is its potential to bridge theoretical concepts in spirometry with the physical instrumentation used to obtain pulmonary function parameters. The graphical display of the respiratory waveform may also facilitate discussion of changes in respiratory volume and airflow during forced expiration. From a technical perspective, calibration syringe testing represents an essential step in assessing whether the measured volume is in close agreement with predefined reference values. In this study, 1-L and 3-L calibration syringes were specified, with five repeated measurements for each reference volume. Once the numerical measurement data are available, they can be used to calculate measurement error and assess measurement consistency.

Accordingly, the primary contribution of this article lies in the integration of a portable spirometer prototype with a practice-oriented medical instrumentation learning framework. The prototype provides a tangible platform through which students can connect physiological principles, spirometric measurement, sensor technology, electronic signal acquisition, and data visualization. Nevertheless, the educational effectiveness of the device has not yet been empirically evaluated. Future research should therefore include student-based evaluation to determine whether the use of the portable spirometer improves learning outcomes, conceptual understanding, and usability in medical instrumentation education.

CONCLUSIONS AND RECOMMENDATIONS

This study resulted in the development of a portable spirometer prototype based on an MPX5500DP pressure sensor, Arduino Uno microcontroller, and Nextion display, designed for the measurement of forced vital capacity (FVC) and forced expiratory volume in the first second (FEV_1), as well as spirogram visualization. The system integrates sensing, data acquisition, microcontroller-based signal processing, and information display, demonstrating potential as a practical learning medium for medical instrumentation education among D3 Radiology students.

Technical testing using 1-L and 3-L calibration syringes was specified in the research design; however, the numerical measurement results were not available in the source document. Therefore, the measurement accuracy of the prototype is not quantified in this article, and no numerical values have been generated or estimated. The accuracy assessment should be completed once the original measurement data are available.

Further research is recommended to evaluate the educational effectiveness of the developed spirometer among D3 Radiology students using a pretest–posttest design. Future studies should also incorporate usability assessment and user experience evaluation to determine the practicality, acceptability, and educational value of the device in medical instrumentation learning.

ADVANCED RESEARCH

Future research should complete the technical performance data of the portable spirometer, including FVC and FEV_1 measurements, measurement error, and repeatability, followed by systematic validation of the device as a medical instrumentation learning medium. Further studies should also evaluate its educational effectiveness among D3 Radiology students using a pretest–posttest design and appropriate statistical analysis to determine changes in learning outcomes, supported by usability and user experience assessments.

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